Name ______________________ **Date** ______________

Phenomenon

Imagine the scene: you and thousands of other fans fill the stadium, attending a sporting event for your favorite team. Suddenly, an excited cheer rises energetically and you see a human-powered wave begin to sweep over the seating sections across the field. In a matter of seconds, you too are swept up in the wave and briefly become a part of it as people stand, arms raised, all around you. The human wave continues, jumping a small seating gap and reflecting off a dead end until it stops to the delighted applause of cheering spectators.

Driving Question

Over the course of this 5-day lab, you will experiment with different types of waves to collect and analyze data and to answer the Driving Question, **"What are some different types of waves, and what do they have in common?"**

Prelab Activity

Materials

Internet-connected computer or device

Procedure

1. Do an Internet search for "stadium wave" videos. Pick the best example you can find and watch it several times. Return to the video clip frequently as you answer the Prelab Questions.
2. Work in a group of four to answer the Prelab Questions.
3. Compare and contrast your responses with those of other groups, and revise and refine your answers on the basis of your class discussion.

Prelab Questions: Making Sense of a Stadium Wave

1. Waves have causes and effects. What is the cause of a stadium wave, and what is its effect? Describe the cause in words, and sketch a simple diagram to show the effect.

2. What properties of a stadium wave could be estimated or measured, and how might you collect that data?

3. It is often easier to describe how a wave looks or behaves than it is to define what a wave actually is. Discuss the following definition of a wave, and decide how it applies specifically to a stadium wave:
   "A wave is a disturbance in which what happens at any given point is a delayed response to the disturbance at neighboring points."

4. The progress of a disturbance is known as **propagation**. Waves propagate through a **medium** such as air, water, glass, a guitar string, an electrical cable, or a vacuum. What medium does a stadium wave travel through? What medium does an ocean wave travel through?

5. For any type of wave, is it the medium or the disturbance that propagates? Use the example of a stadium wave to explain your answer.

Name ______________________ **Date** ______________

Materials

For two groups

metal coiled springs, 2
metric rulers, 2
metersticks, 2
stopwatches or timers, 2
masking tape (shared)

Seismic Waves

In the Prelab you considered the properties of stadium waves. At this investigation station you will model primary and secondary waves created by earthquakes. Look for the properties that these waves have in common with stadium waves and the waves you study at the other investigation stations.

Background

This activity models **seismic waves** that are caused by earthquakes. Earthquakes occur when underground rocks fracture at a fault, releasing tremendous amounts of energy. Energy is transmitted in all directions from the earthquake's source, or **focus**. The point on Earth's surface directly above the focus is called the epicenter.

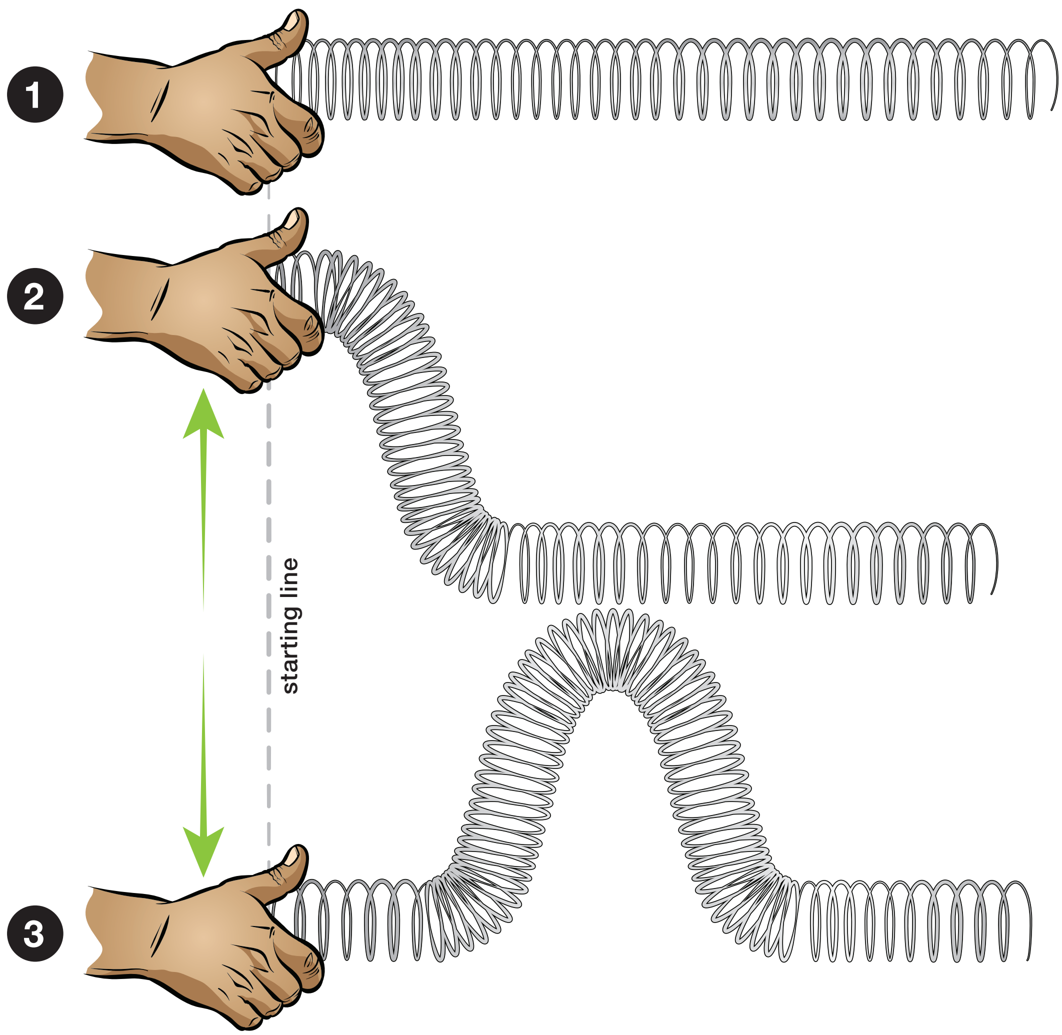
Primary waves (P waves) are the first waves to be detected after an earthquake. P waves travel from inside the earth toward the outside. They move quickly through rock, liquids, or air and can reach the opposite side of Earth in as few as 20 minutes. P waves are longitudinal waves that shake the medium back and forth parallel to the direction of movement of wave energy.

Shear waves (S waves) are waves that can move from side to side (S-Horizontal, SH) or up and down (S-Vertical, SV). In both cases, the transverse wave's particle movement is perpendicular to the direction of energy transmission. Shear waves move only through solid rock and are much slower than primary waves. Geologists commonly call shear waves "secondary waves."

Activity A

Procedure

1. Measure a distance of 120 cm on a table or floor. Mark each end with a piece of masking tape.
2. Have one student hold the end of the coiled spring stationary at one tape strip (the finish line) while another student stretches the free end back to the other tape strip (the starting line). In each case, use two hands to hold the last coil of the spring.
3. The student at the starting line should move the spring quickly about 15 cm to the left and then back to the center. This models one wave pulse.



4. Repeat this single pulse wave several times and make careful observations. Notice how the direction of the spring's displacement compares with the direction of the traveling wave pulse. You can model the wave pulse again as necessary while you answer the following questions.

Stop and Think

a. Describe what the wave pulse looks like. What happens when it reaches the end of the spring?

b. How does the direction of the spring's disturbance (side to side) compare to the direction of the propagating wave? In the space provided, draw a simple diagram to explain your answer.

c. What part of the model represents the medium, underground rock? How does it represent the energy released from a rock fracture? How does the model represent how earthquake energy travels from the rock fracture to other places underground?

d. The **amplitude** of a wave measures the maximum amount of displacement of the medium from its rest position. Label the amplitude of the wave pulse diagram you created for the answer to Question b.

e. How does the amplitude of the outgoing wave pulse compare with the amplitude of the wave pulse on the return trip?

5. Repeat Step 3, but have one student measure the time in seconds for a single wave pulse to make a "round trip." Do this three times, and calculate the average time. Use the average time and round trip distance to calculate the speed of the wave in cm/s. Record the times, average time, and the speed in the the table provided.

Trial 1: ________s	Trial 2: ________s	Trial 3: ________s	Average = _______s	Speed = _______cm/s

Analysis

1. Did the Activity A model represent P waves or S waves? Give evidence to support your claim.

2. **Reflection** can occur when a wave hits a boundary. Echoes you hear consist of reflected sound waves. Mirror images you see are made by reflected light waves. Earthquake waves can also reflect when they hit boundaries. How did the Activity A model demonstrate reflection?

3. A wave is a disturbance that transfers energy, not matter, from one place to another. How does the Activity A wave model support this?

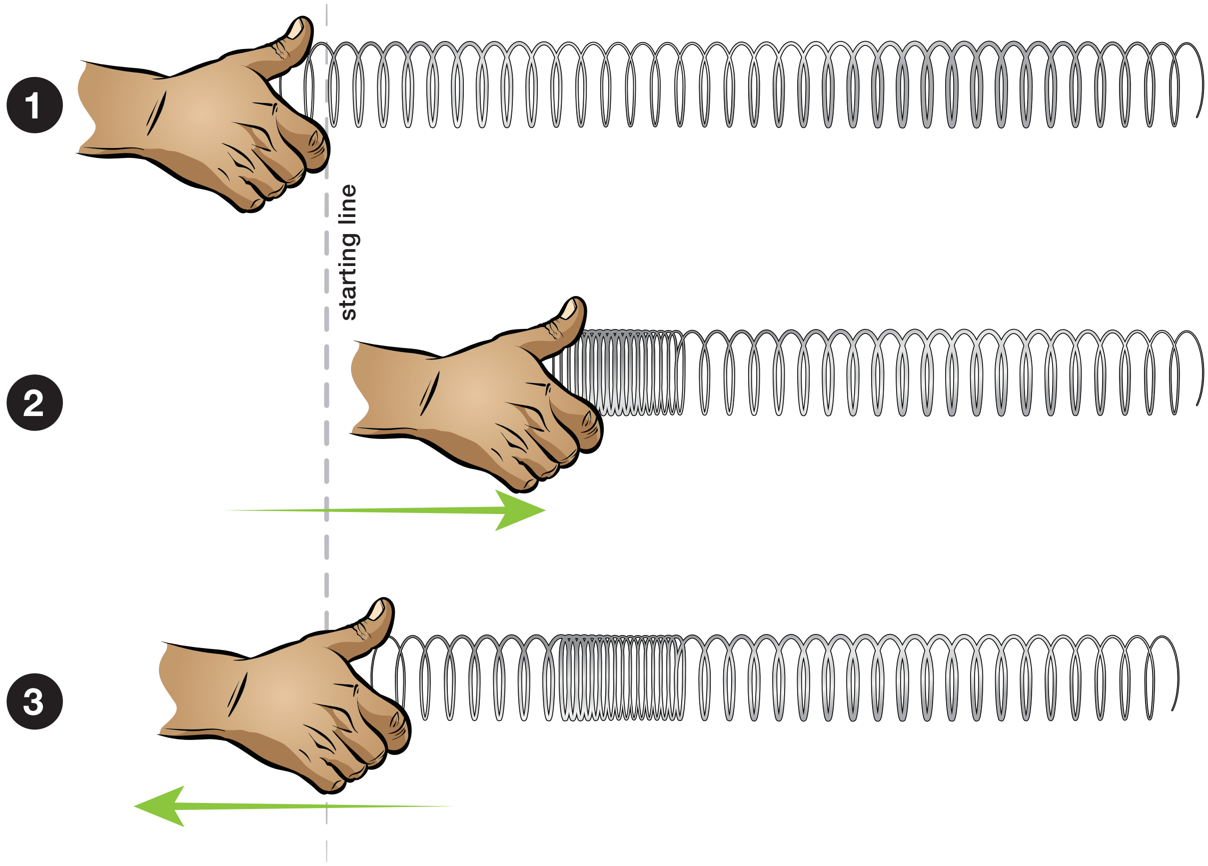
4. The energy of a seismic wave decreases as the energy released by the earthquake spreads throughout a larger volume of the earth. What evidence from your Activity A model supports this phenomenon?

5. What do stadium waves have in common with the seismic wave pulses you modeled with the coiled spring in Activity A?

Activity B

Procedure

1. As in Activity A, use the distance of 120 cm marked with masking tape.
2. Have one student hold the end of the coiled spring stationary at one tape strip (the finish line) while another student stretches the free end back to the other tape strip (the starting line). In each case, use two hands to hold the last coil of the spring.
3. Quickly move the starting line end of the spring approximately 10 cm forward and backward. This creates one pulse of a compression wave. It should travel the length of the spring, reflect off the stationary end, and return to its origin.



Stop and Think

a. Describe what the wave pulse looks like. What happens when it reaches the end of the spring?

b. How does the direction of the spring's displacement (forward and back) compare to the direction of the traveling wave pulse? In the space provided, draw a simple diagram to explain your answer.

c. The amplitude of the Activity B wave model is a bit difficult to see. The amplitude is the distance from the equilibrium or resting position of the spring to a bunched-up compression (or to a stretched-out portion described as a **rarefaction**). Watch a few outgoing and returning wave pulses. Does the amplitude appear to increase, decrease, or remain the same as the pulse returns? What does this look like?

4. Repeat Step 3. This time, one student should measure in seconds the time required for one compression wave pulse to make a "round trip." Do this three times, and calculate the average time in seconds. Use the average time and round trip distance to calculate the speed of the wave in cm/s. Record the trial times, average, and speed in the table provided.

Trial 1: ________s	Trial 2: ________s	Trial 3: ________s	Average = _______s	Speed = _______cm/s

As P waves and S waves from an earthquake reach Earth's surface, they generate complex surface waves known as Love waves and Rayleigh waves (named after the scientists who first mathematically modeled them). A Love wave is a surface transverse wave, moving side-to-side perpendicular to the direction of wave energy. A Rayleigh wave is a slower wave; it resembles an ocean wave. The ground rolls up and down as the wave moves forward in a given direction. If you were to view Rayleigh waves approaching, the ground would look like ripples on a body of water. The effect as Rayleigh waves pass is like standing on a boat deck in a choppy sea.

5. Model the complex surface wave interaction by sending two wave pulses toward one another. Have one person send a transverse pulse and the person at the other end send a longitudinal pulse. Closely observe the two wave pulses after they meet.

Stop and Think

d. Describe the interaction of the two waves. How is this interaction more complex than an individual P wave or S wave?

6. Pinch a group of coils near the center of the spring and quickly release. Try this several times, adjusting the number of coils you pinch together (start with about a 1-inch section) and the tension of the spring until you create an effect that is easy to see.

Stop and Think

e. Describe the effect created in Step 6. What characteristic of earthquakes does this model? Explain.

Analysis

1. Did the Activity B model represent Primary waves or Shear waves? Give evidence to support your answer.

2. P waves generated by an earthquake travel faster than S waves. Were your models able to demonstrate this? Give evidence to support your answer. If the models did not demonstrate that P waves are faster, discuss a limitation of your model that could account for the variation.

3. In the space provided, create a Venn diagram that compares and contrasts P and S waves.

4. Now that you have completed this modeling station, what is a question you have about seismic waves, or waves in general? How could you find an answer to your question?

Name ______________________ Date ______________

Materials

For two groups

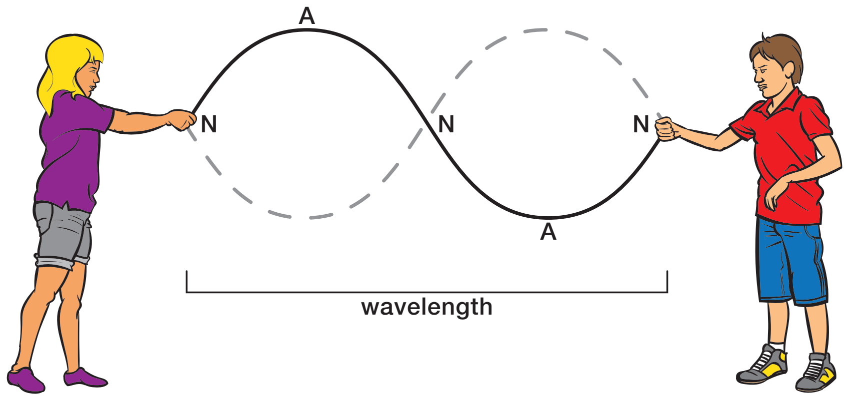
coiled metal springs, 2
metersticks, 2
stopwatches or timers, 2
masking tape (shared)

Standing Waves

Stadium waves and surface waves on the ocean are examples of waves that travel. At this investigation station you will model **standing waves**, which appear not to travel. Figuring out how to shake a coiled metal spring just right so that it snaps into a standing wave pattern is fun, and these large standing waves make it easy to identify wave properties that all waves have in common.

Background

A standing wave can be created when waves going in opposite directions interfere with each other in a specific way. Each pulse of the wave that is created reflects when it reaches the opposite end, causing interference between the reflected wave and the next wave that is generated. At locations where the waves cancel each other, called **nodes**, the spring appears to be at rest. In other locations, called **antinodes**, constructive interference creates a place of maximum spring movement. One **wavelength** consists of two antinodes.



Procedure

1. Measure a distance of 120 cm on a table or floor, and mark each end with a piece of masking tape.
2. Have one student hold the end of the coiled spring stationary at one tape strip (the finish line) while another student stretches the free end back to the other tape strip (the starting line). In each case, use two hands to hold the last coil of the spring.
3. Create a standing wave pattern that consists of two antinodes by shaking one end of the coiled spring left-to-right at a steady rate while the opposite end is held steady. Have each group member give it a try.
4. Now have each group member try to create a standing wave pattern that has three antinodes.

Stop and Think

a. In the space provided, sketch the 3-antinode wave pattern. Label the nodes, antinodes, and one wavelength.

b. How many complete wavelengths are present in the 2-antinode standing wave pattern?

c. How many complete wavelengths are present in the 3-antinode standing wave pattern?

5. Recreate the wave pattern with 2 antinodes, and then immediately change the pattern so there are 3 antinodes. Have each group member give this a try.

Stop and Think

d. The number of wavelengths that pass a point in a given amount of time (for example, one second) determines a wave's frequency. In your standing wave model, the number of back-and-forth shakes you make per second is the standing wave's **frequency**. How did your shaking frequency change when you went from the 2-antinode wave pattern to the 3-antinode pattern? Which wave pattern has the higher frequency?

e. Compare the wave pattern that had the higher frequency to the one with the lower frequency. How did their wavelength measurements compare? (**Tip:** Use the illustration and your sketch to help you with this, or use a meterstick to take actual wavelength measurements.)

6. Recreate the 2-antinode pattern, but try to gradually increase the distance of the side-to-side movements of the spring while maintaining the same frequency. Practice this skill several times before you make final observations.

Stop and Think

f. The distance from the spring's resting position to an antinode is the wave's **amplitude**. Did the amplitude increase or decrease in Step 6? Was it easier or more difficult to create this wave pattern, compared to the first pattern you created?

g. Amplitude is an indicator of a wave's energy. Did the new wave pattern have more or less energy than the first pattern? Use evidence from your experience to support your claim.

Analysis

1. Are wavelength and frequency directly related or inversely related? Give evidence to support your answer.

2. The **period** (T) of a wave is the time it takes for one complete cycle—in the case of your wave model, the time it takes to move the coiled spring from one side to the other and back again. If you time how long it takes for 10 complete cycles, how could you calculate the average time for one cycle to occur, in units of seconds per cycle (s/cycle)?

3. The frequency (f) of the wave is how many cycles per second occur. How does the unit for frequency, cycles per second (cycle/s), compare to the unit for period, seconds per cycle (s/cycle)? What does this tell you about the relationship between period and frequency?

4. Consider the units for frequency (cycle/s) and wavelength (m/cycle). What mathematical operation can be performed on these quantities that would result in a unit of **speed** (distance covered per unit of time)?

5. What is a question you have about standing waves? How could you, experimentally or mathematically, find an answer?

Name ________________________ **Date** ________________

Materials

For two groups

tuning forks, 512 Hz, 2

tuning forks, 384 Hz, 2

tuning forks of unknown frequency, 2

plastic tubes with open ends, 2

plastic tubes with one closed end, 2

plastic trays with hole in center, 2

400-mL beakers filled with water, 2

tuning fork activator (shared)

Sound Waves

Have you ever played a musical instrument or even blown air over an open bottle to hear the sound created by the vibrating air column? We hear sound from instruments because standing waves produced inside the tube or along the string of an instrument are amplified. The amplification of these sound waves is known as acoustic **resonance**. At this investigation station you will use a vibrating tuning fork to move air inside a column to experiment with resonance.

Background

When you repeatedly push the end of a coiled spring, you can create compression waves all long the spring. When you repeatedly push air molecules, you can create sound waves. One way to repeatedly push air molecules is to hit a tuning fork. When struck, the vibrating prongs will repeatedly push air molecules. If you hold the vibrating tuning fork near your ear, or place the stem down on a table, your ear will detect the single tone that the tuning fork has been designed to create. The number of vibrations the prongs undergo in a second is known as the tuning fork's **frequency** in Hertz (Hz).

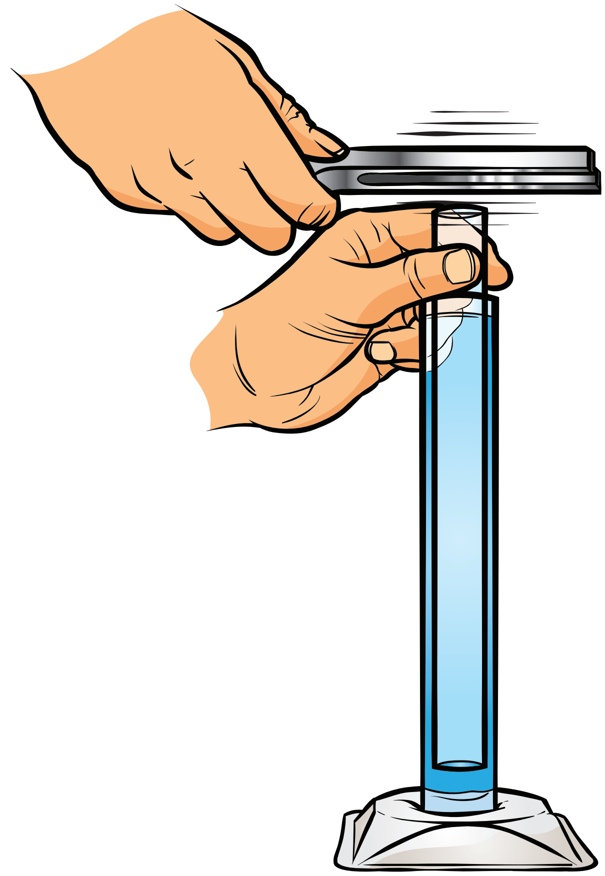
Setup

1. Turn the white tray with the hole in the center upside down.
2. Insert the closed end of the large tube into the hole in the tray until it rests on the table.
3. Adjust the tray height until it forms a supportive base for the cylinder.
4. Take some time to observe the three tuning forks. Notice that two of them have known frequencies, and one has an unknown frequency.
5. *Set the unknown fork aside for now* and activate each of the known tuning forks, separately, by hitting the edge of one prong against the activator and listening for the tone.
6. Look for other things, besides the quality of the tones, that are unique about each fork.

Procedure

1. Fill the large tube with water to just below the top.
2. Hold the smaller plastic tube vertically over the larger tube and insert the end of the smaller tube to just below the water's surface.
3. Strike the 512-Hz tuning fork on the activator and place the vibrating prongs horizontally (flat) over the mouth of the small plastic tube without touching the tube.

4. Keeping the vibrating fork over the top of the small tube, lower the small tube farther and farther into the water and observe the nature of the sound produced in the small tube's air column. Repeat this until you notice an interesting sound phenomenon.



Stop and Think

a. Waves have causes and they have effects. What is the cause and effect associated with the sound waves produced in the air column below the tuning fork?

b. What phenomenon did you observe as you changed the length of the air column? Record any necessary measurements for the 512-Hz fork so that you can refer back to this experience without having to repeat it.

5. Repeat steps 3 and 4 with the 384-Hz tuning fork.

Stop and Think

c. What phenomenon did you observe as you changed the length of the air column? Record any necessary measurements for the 384-Hz fork so that you can refer back to this experience without having to repeat it.

d. Compare and contrast the sound phenomenon created by the two tuning forks.

6. Observe the tuning fork with the unknown frequency, but *do not use it to vibrate the column of air yet*.

Stop and Think

e. Make a prediction as to how the sound phenomenon in the air column created by the unknown tuning fork will compare to those of the known forks you have already studied. Explain your reasoning.

7. Repeat Step 3 and Step 4 with the unknown tuning fork. Record any necessary measurements.

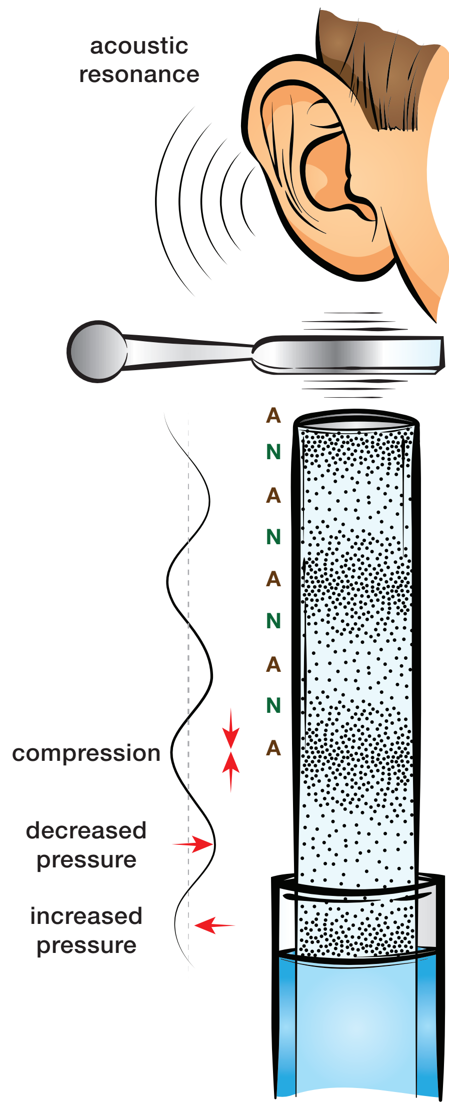
Analysis

1. Compile the data you collected about the tuning forks in an easy-to-read data table.

2. How did your prediction for the unknown tuning fork compare to your results? Discuss.

3. Your ear could detect when the length of the vibrating column of air was "just right" for a particular sound wave frequency. This length is proportional to the **wavelength** of the wave produced at that frequency. Based on the evidence you collected, are the properties of frequency and wavelength related inversely or directly? Explain.

4. Regular, repeated vibrations of the tuning fork cause air molecule compression wave pulses of that same frequency to become trapped in the small tube. For these waves, which are **standing waves**, areas of maximum amplification of the sound waves occur at **antinodes**, where the wave amplitude is greatest. Areas of zero volume or no sound occur at **nodes**, where wave amplitude is at the minimum. Study the illustration at right, which shows an example of acoustic resonance.



a. The water's surface at the bottom of the air column forces the standing wave to have a node at that spot, much like how pressing a fret on a guitar forces a vibrating string to have a node. Only when the length of the air tube or the placement of a fret on a guitar string is at one specific place will acoustic resonance happen. Why? Refer to the acoustic resonance illustration in your answer.

b. Refer to the acoustic resonance illustration. Suppose you lowered the air column until it was completely submerged in the water. Could the sound phenomenon be heard more than once? Why or why not?

c. In your investigation, did acoustic resonance happen at more than one location for one particular tuning fork frequency? Why or why not?

5. What is a question you have about sound waves? How could you find an answer?

Name ______________________ **Date** ______________

Materials

For two groups

semicircular dishes, 2
flashlights, 2
index cards with slit, 2
100-mL graduated cylinders, 2
Protractor Sheets, 2
250-mL beakers, half-full of water, 2
straws, 2
binder clips, 2

Light Waves

Recall the stadium wave phenomenon you studied in the Prelab. Imagine that one seating section in a large, round stadium is enclosed in a wall of water (and the fans can breathe normally, of course). A crowd wave begins several sections away from the submerged section. Once the wave arrives at the underwater seats, what do you think will happen to the wave's speed as it propagates through the aquatic section, and why? This wild scenario is one way of considering the question of what happens when a wave moves from one medium to a different, more dense medium—such as from air to water. At this investigation station, you will see what happens when light waves move from air to water. It is mind-bending, for sure!

Activity A

Background

1. Place a straw in a 250-mL beaker that is half full of water.
2. Hold the beaker up and look at the straw from the side; then look at the straw from above.
3. In the space provided, sketch what you see from different angles.

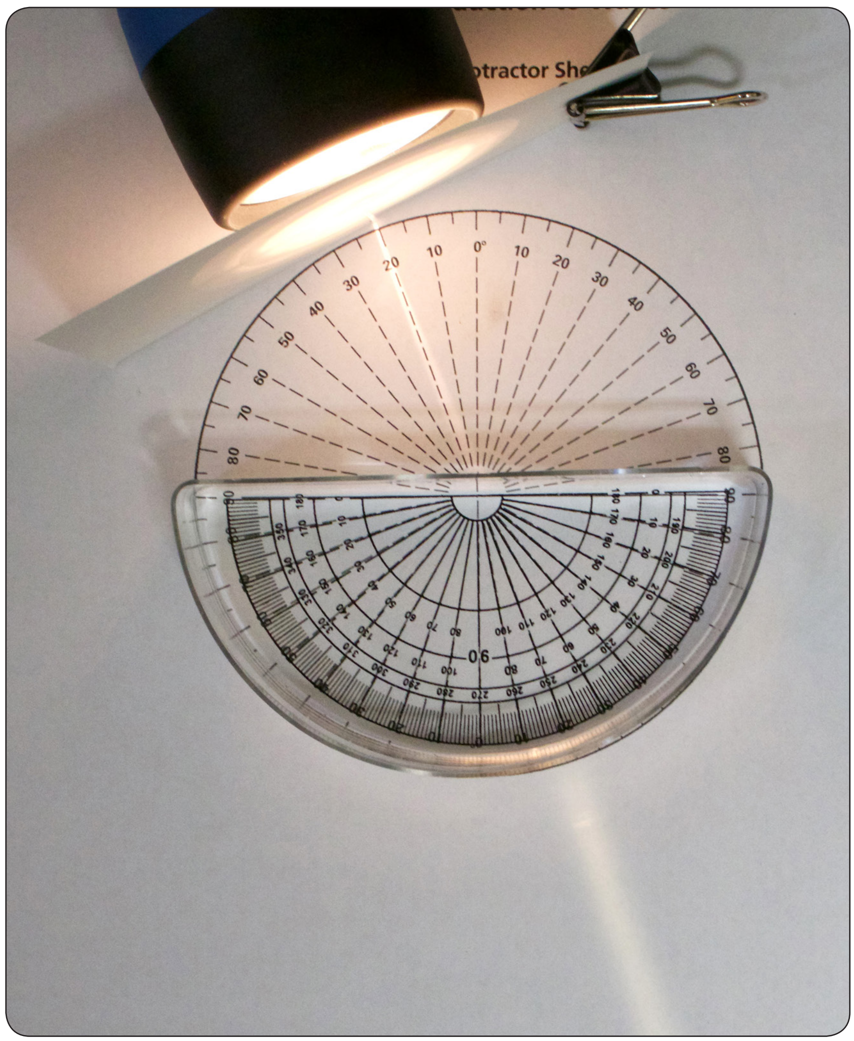
Stop and Think

What is surprising about your observations? Explain what you think causes this interesting effect.

Activity B

Background

1. Place the protractor sheet on a flat surface.
2. Place the semicircular dish on the bottom half of the 360° circle on the protractor sheet.
3. Align the base line of the protractor image on the dish with the dark line that bisects the circle on the paper.
4. To center the dish, align the vertical 90° line of the dish protractor with the 0° line of the circle. The other degree lines on the dish should align with the degree lines on the bottom half of the circle.
5. Measure 100 mL of water with a graduated cylinder and carefully pour the water into the dish without moving it.
6. Use a binder clip to create a stand for the index card. Stand the card on edge, with the slit in the center at the bottom. Attach the clip to the lower right edge of the card. Adjust the clip until it allows the card to stand on its own.
7. Place the slit of the card on the top left side of the protractor at the beginning of the 20° line that is left of the normal 0° line.
8. Another student will turn on a flashlight and place it directly behind the slit at the 20° mark.
9. The flashlight can be rolled left or right until the ray of light is exactly over the dotted 20° line that passes through the center of the circle.
10. Observe the ray as it passes through the water. Does its path change? If so, how does it change? If it is difficult to see the exact path of the ray in the water, bend the paper upwards so the light makes a mark on the paper close to the dish.



Stop and Think

a. The flashlight beam that was directed through air along the 20° line is known as the **incident ray**. When the ray passes into the water, the beam is called the **refracted ray**. Based on what you observed, what is meant by the term “refracted?”

b. The incident ray entered the dish at an angle of 20° from the 0° reference line, also known as the “normal line.” The normal line traces the path that a light ray would take *if it passed into the new medium perpendicularly to its surface*. How many degrees from the normal line was the refracted ray? Repeat the experiment if necessary to make your measurement.

Making Ray Diagrams

1. Make a mark on your protractor sheet that shows how many degrees from the normal line your refracted ray was for the 20° incident ray.
2. Repeat the experiment for incident rays that are 40° and 60° from the normal line. Mark your protractor sheet to show how many degrees from the normal line the resulting refracted rays are.
3. Put the dish of water aside. Using colored pencils and a ruler, trace the incident and refracted rays on the protractor sheet. Each incident/refracted ray pair should have its own color so it is easy to see the paths when you analyze the data.

Analysis

1. What do all of the refracted rays have in common?

2. Reconsider the interesting effect you noticed in Activity A. Revise your explanation of this phenomenon on the basis of what you observed and measured in Activity B.

3. Waves are refracted when they travel from one medium to another medium of different density due to a *change in speed of the wave*. Refraction does not just happen in light waves. Refraction is a characteristic that all waves have in common. Ocean waves coming toward a straight shoreline come almost straight in toward a beach, no matter what their original angle or orientation was. How could refraction explain this phenomenon?

4. Lenses, such as those in a pair of glasses, can correct blurry vision. What did you learn from this station that could help explain how lenses work?

Name ______________________________ **Date** ____________________

1. Throughout the investigations, you explored different types of waves. You gathered evidence of how waves behave and interact. Revisit the Driving Question for this investigation: **"What are some different types of waves, and what do they have in common?"** Consolidate information and evidence from the Prelab and all four stations to describe at least three properties or characteristics that all waves have in common. As you describe the properties, provide evidence from the stations to support your answer.

2. Work with your classmates to organize a sharing of your answers to the Driving Question. Were there any wave properties that others described that you did not? List any that apply.

3. A wave is a disturbance that transfers energy from one place to another without transferring matter. Describe evidence from two (or more) investigation stations that supports this central concept.

4. Compare and contrast electromagnetic and mechanical waves. Give examples from each station to support your comparison.

5. You created transverse standing waves with the coiled spring at one of the investigation stations. Can standing waves be longitudinal? What evidence do you have from one or more investigation stations to support your answer? Explain.

6. What is one question that you have about waves? Could you expand on one of the station models or experiments to answer that question? Discuss.

Protractor Sheet